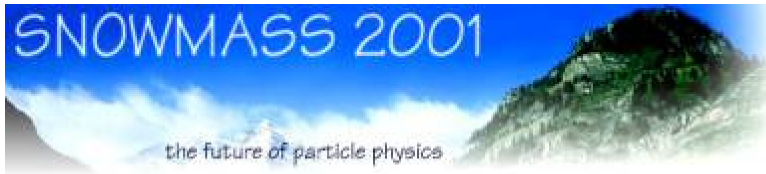
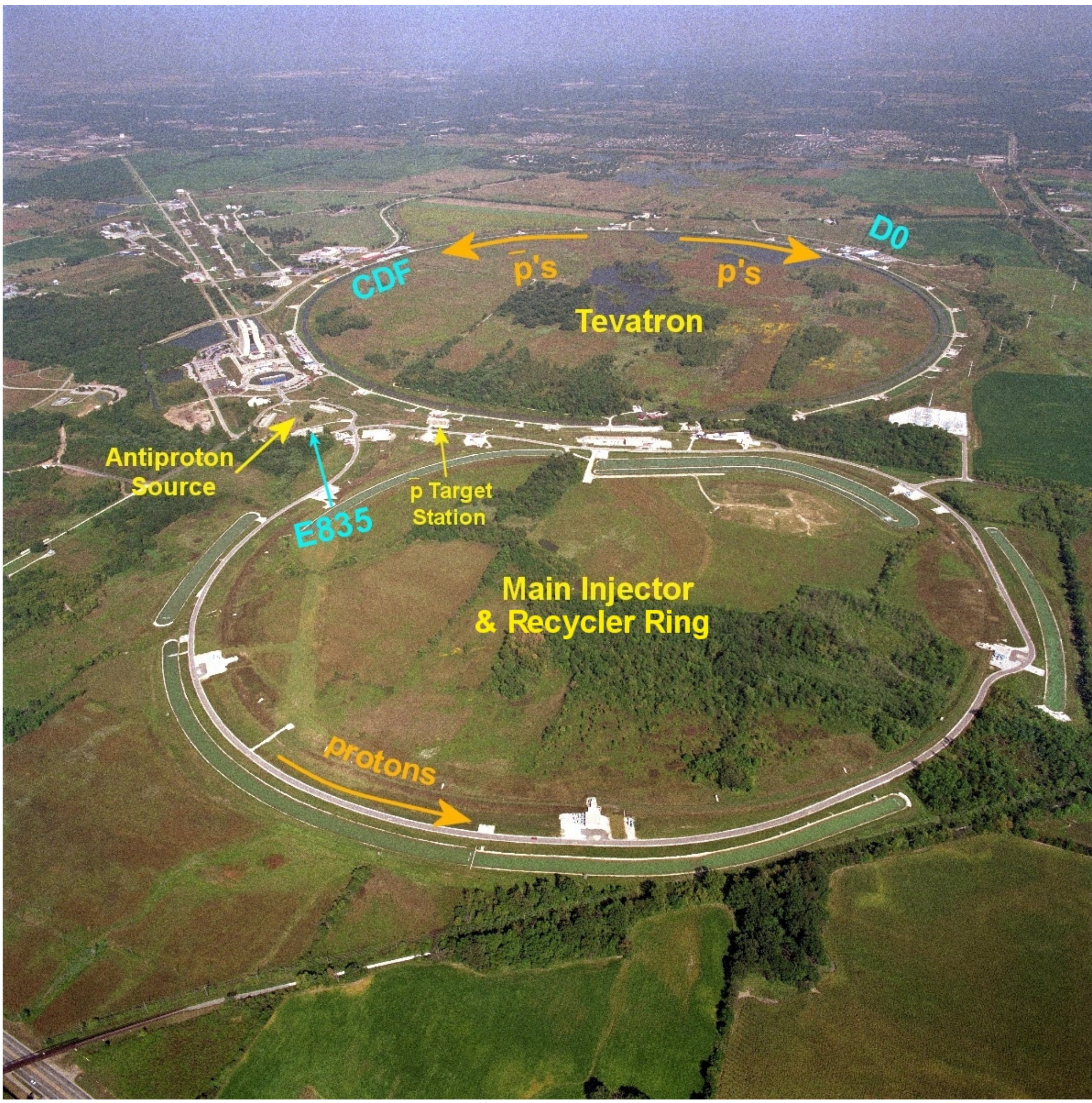


Antiproton Production Overview

- ***The Big Picture***
  - Why make $\bar{p}$'s
  - Integrated operation of the Fermilab Accelerator Complex:
    - Targetry and collection
    - Bunch Rotation
    - Stochastic Cooling
    - Momentum stacking
- ***Present performance***
  - Near term goals
  - Limitations to $\bar{p}$ production
    - Protons on target
    - Production target and collection limitations
    - Stochastic Cooling technology
    - Trapped ions
- ***Upgrades and expected future performance***
  - Recycler Ring
  - Slip Stacking

The Big Picture

The Fermilab Accelerator Complex

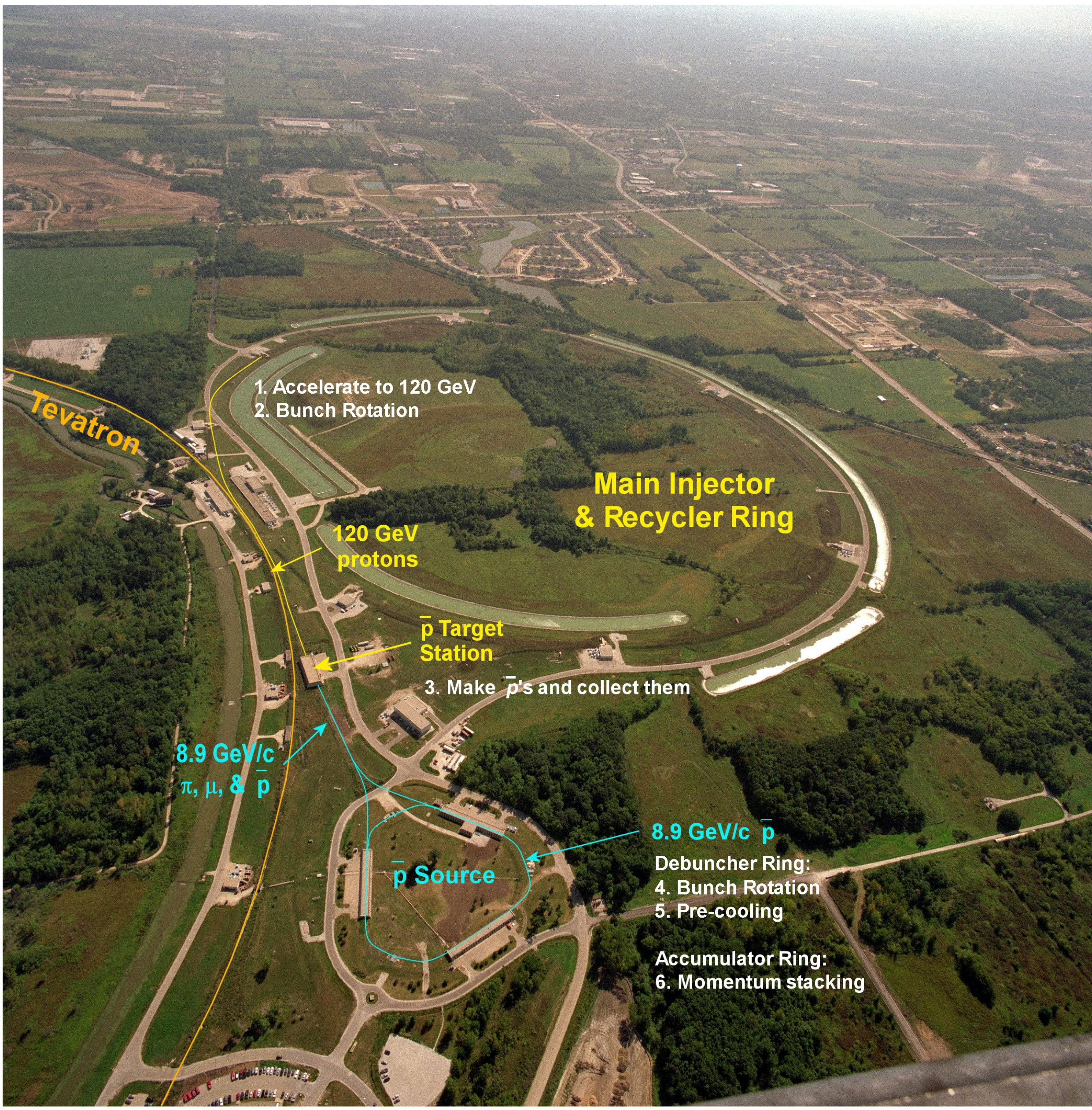


Six Step Procedure for making $\bar{p}$'s

1. Accelerate 82 intense proton bunches to 120 GeV. (Linac – Main Injector)
2. Rotate the proton bunches ¼ turn in longitudinal phase space to minimize the bunch length. (Main Injector)
3. Direct this beam to a nickel target every 1.5 to 4.0 seconds and collect with a lithium lens for transport to the Debuncher. ($\bar{p}$ Target Station)
4. Rotate the 8.9 GeV $\bar{p}$ bunches another 90º in longitudinal phase space to minimize the energy spread. (Debuncher)
5. Pre-cool the beam and transfer to the Accumulator. (Debuncher)
6. Add freshly injected $\bar{p}$ beam to those already accumulated using longitudinal stochastic cooling. (Accumulator)

$\Rightarrow$ ***Repeat steps 1 through 6***

Six Step Procedure for making $\bar{p}$'s



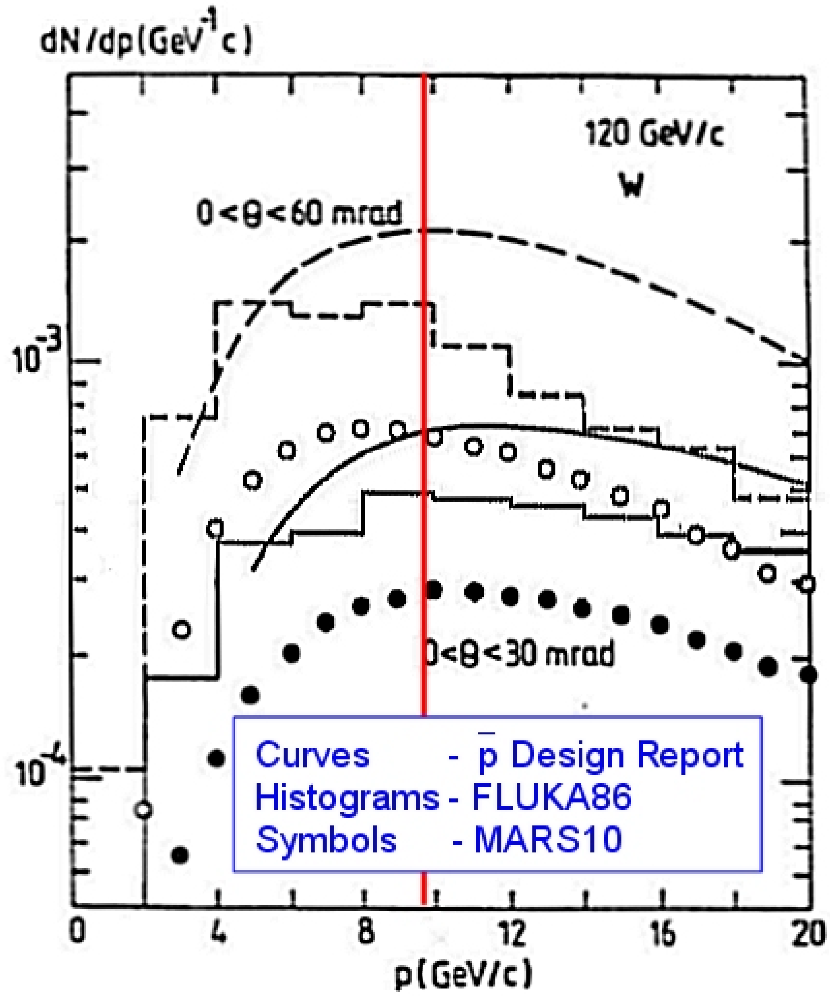
$\bar{p}$ production as a function of $\bar{p}$ energy

Notes:

1. The peak yield for 120 GeV incident protons is at a $\bar{p}$ momentum of ~10 GeV/c.

2. The yield curves are essentially flat between 8 GeV/c and 12 GeV/c.

3. Most $\bar{p}$ production occurs at θ < 30 mrad.

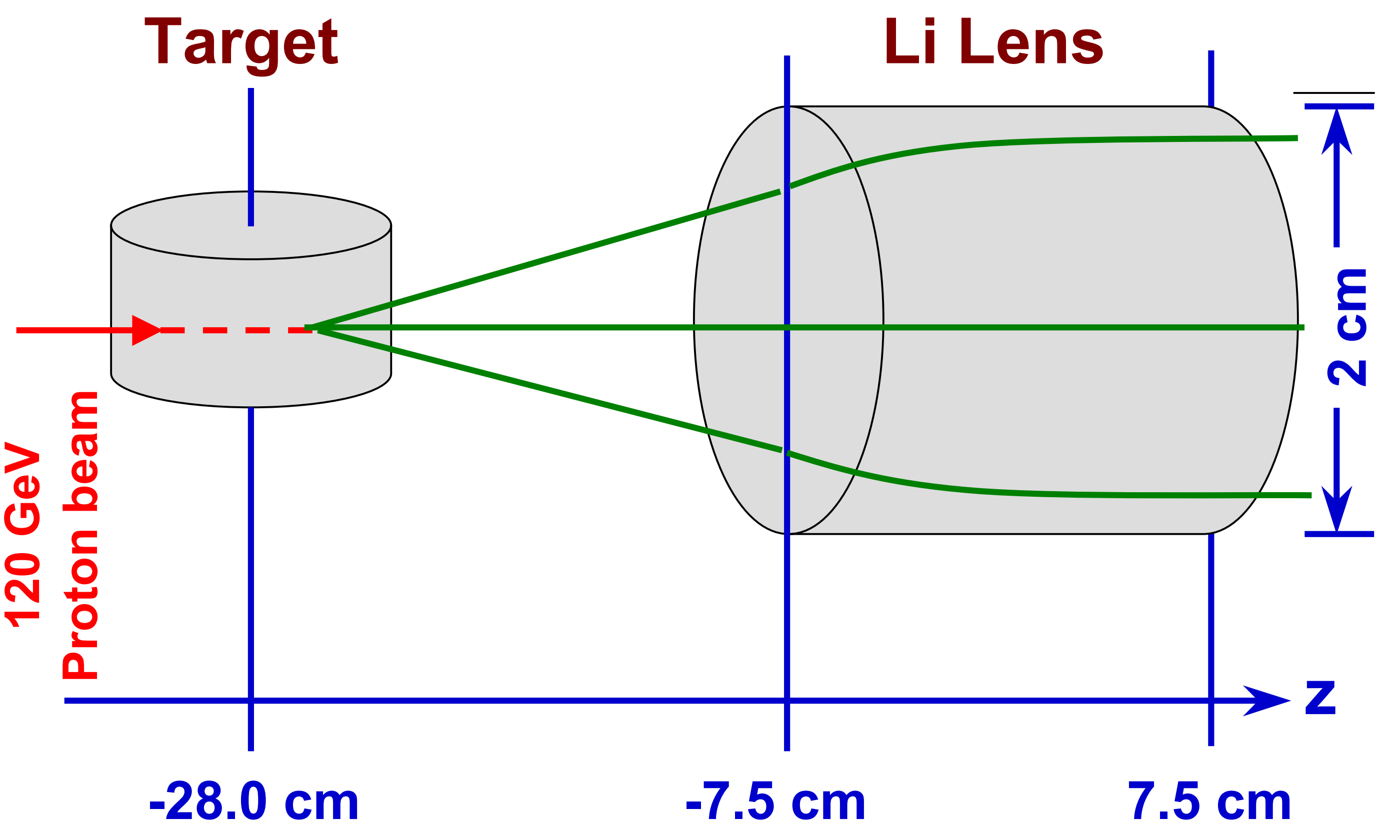


$\bar{p}$ yield versus $\bar{p}$ momentum for 120 GeV incident proton beam on a tungsten target.

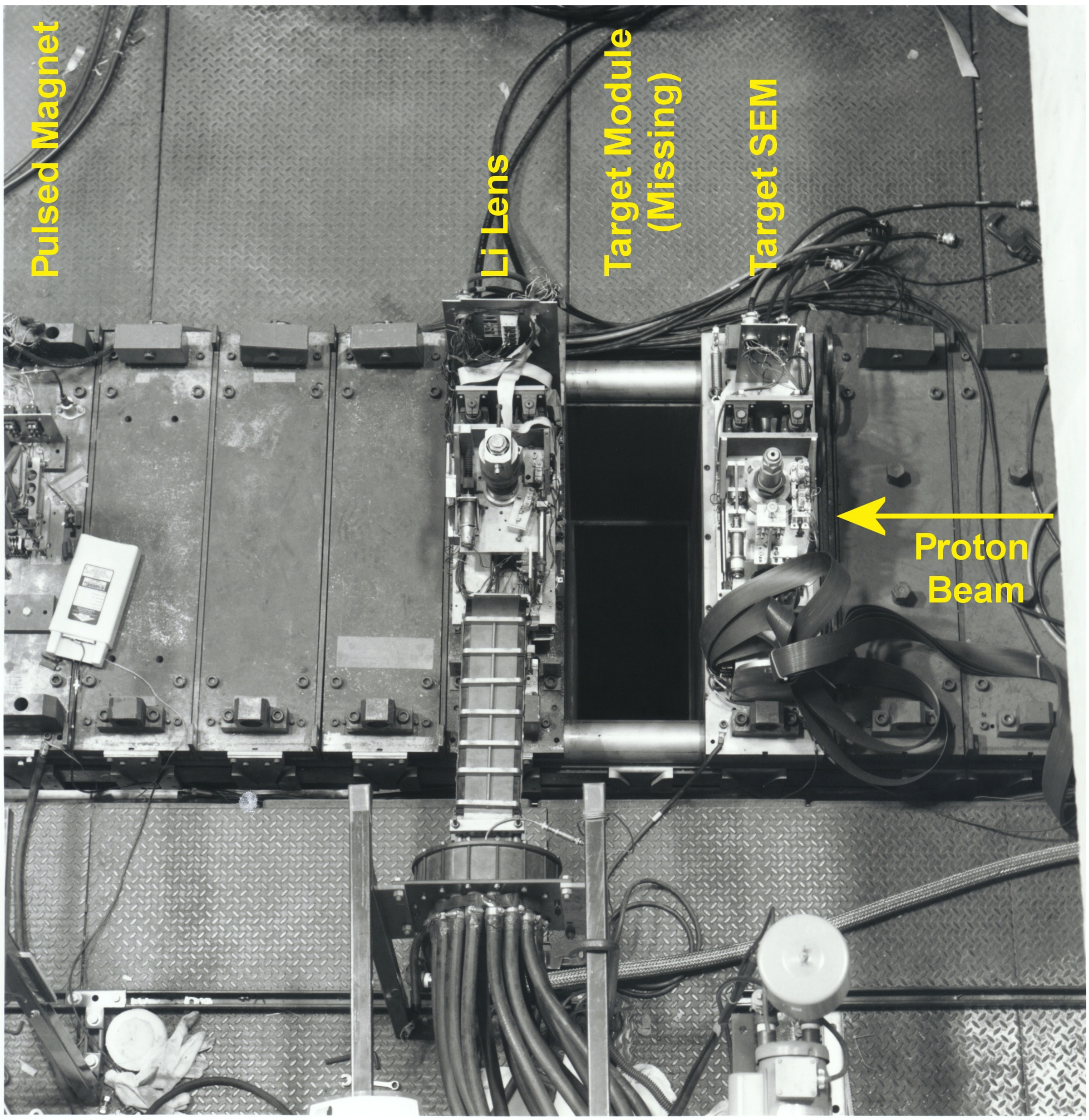
From: I.L. Azhgirey, N.V.Mokhov, and S.I. Stringanov, FERMILAB-TM-1730

Target Station Layout

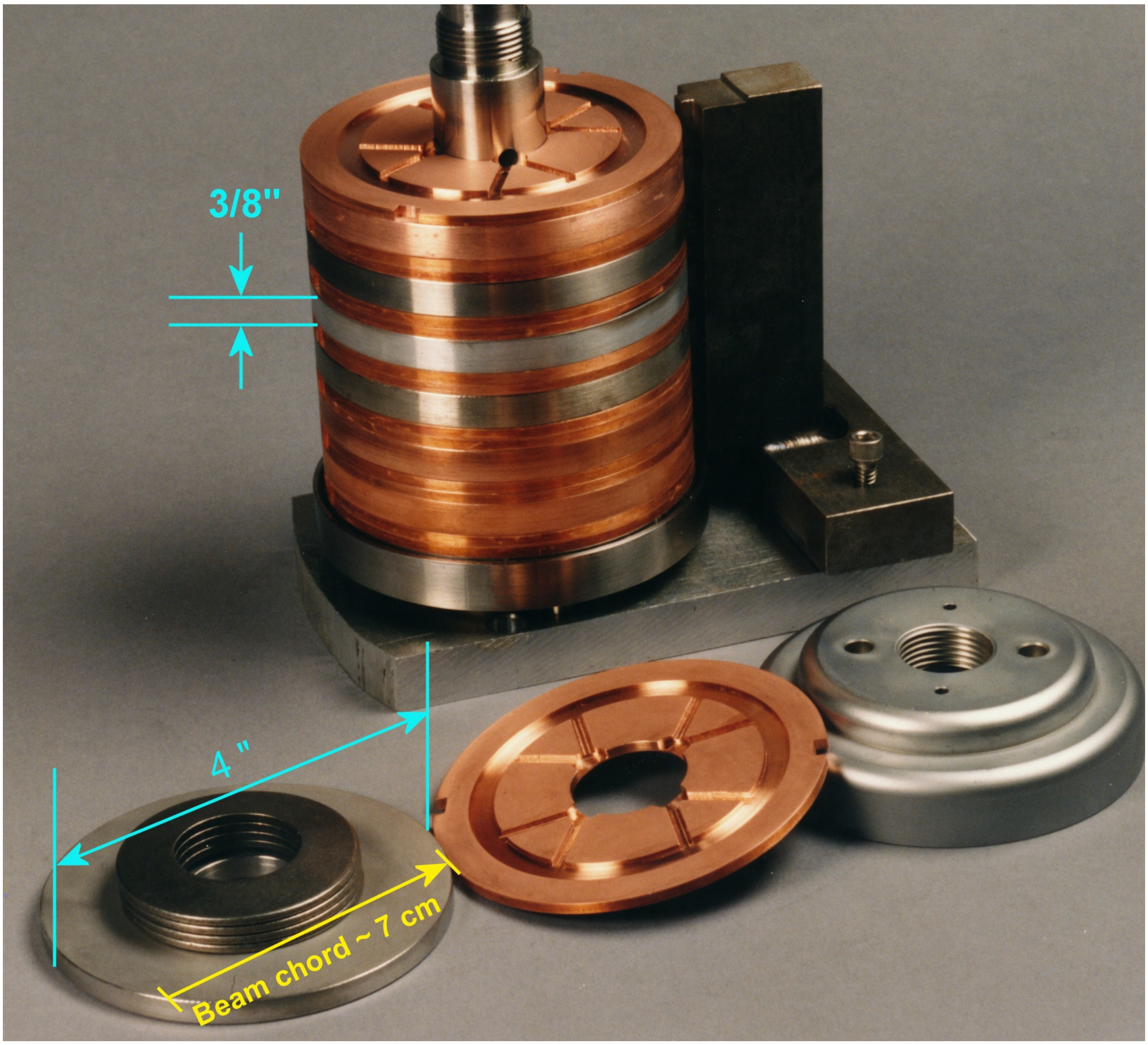
Proton Beam Parameters	
Intensity	5.0×10^{12} p/pulse
$\Delta p/p$	$\pm0.15\%$
σ_x	0.14 mm
σ_y	0.23 mm



Overhead view of Target Station



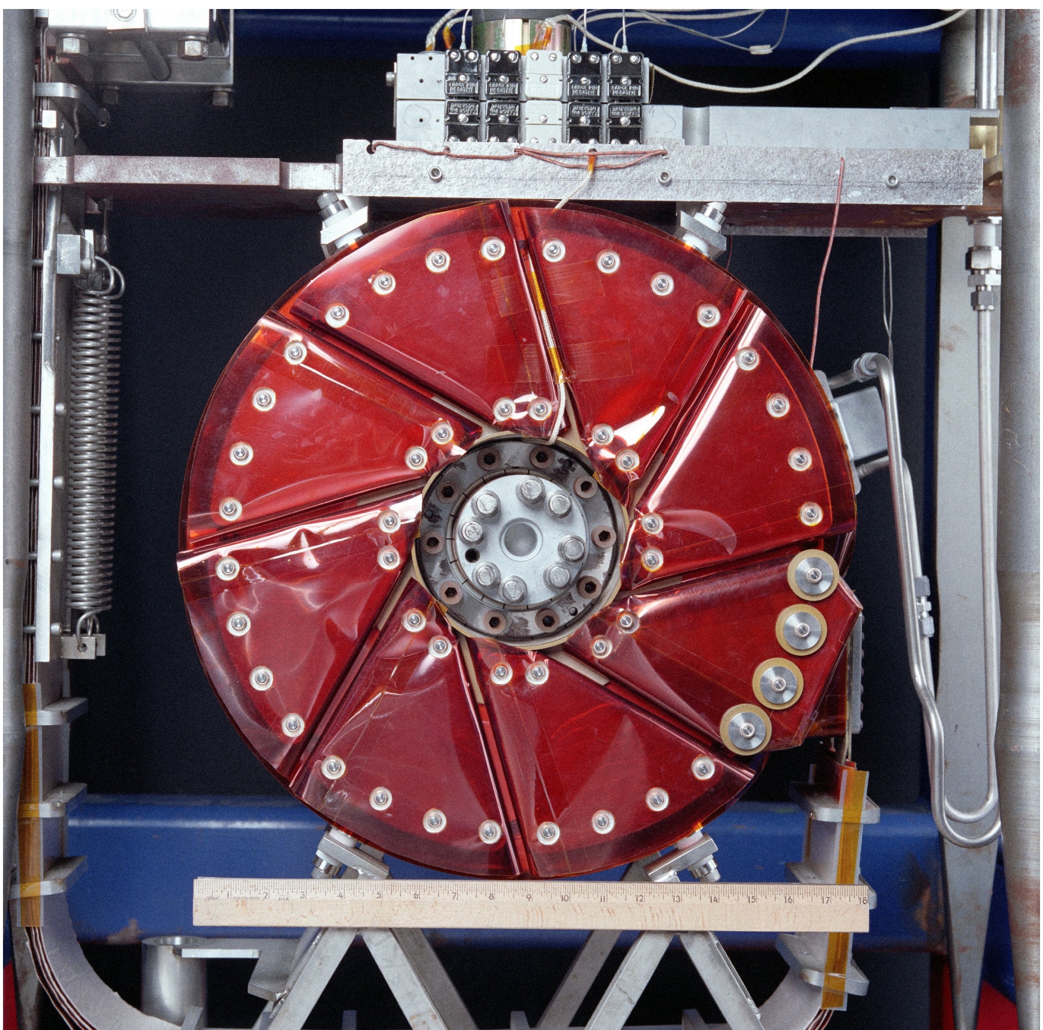
$\bar{p}$ Production Target



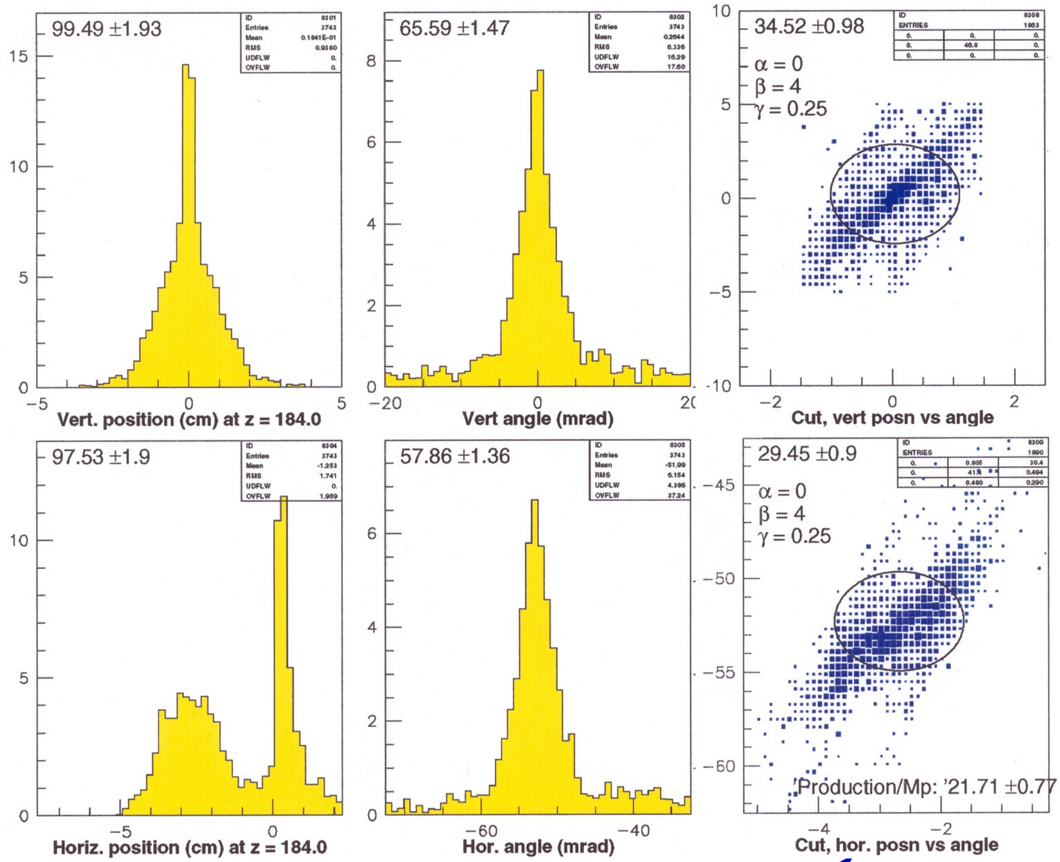
The $\bar{p}$ production target consists of several disks of nickel target material separated by cooling disks. The entire stack rotates slowly at ~1°/5 sec.

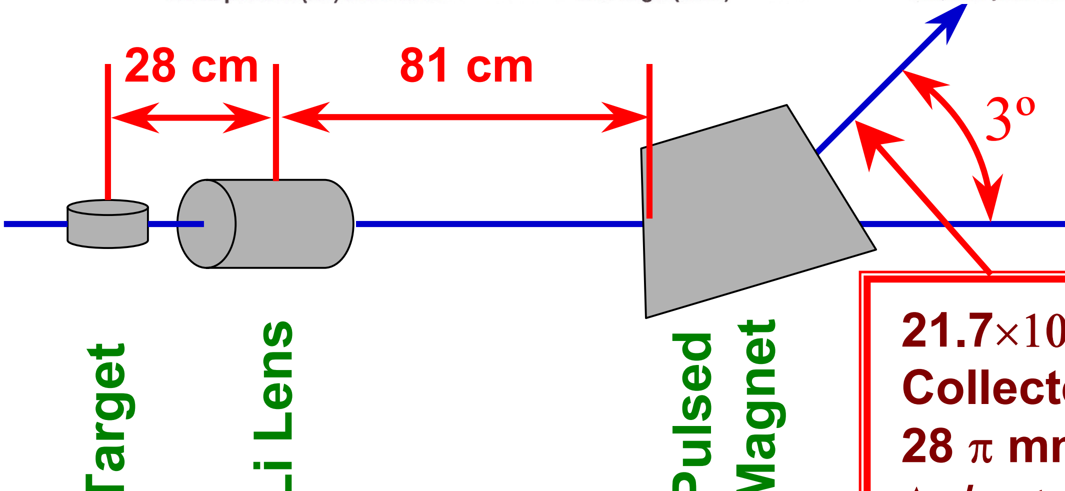
Lithium Collection Lens

Lithium Lens Parameters	
Gradient	750 Tesla/m
Radius	1 cm
Length	14.5 cm



$\bar{p}$ Phase Space Collected





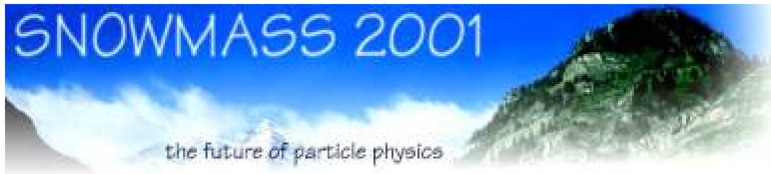
21.7×10^{-6} $\bar{p}/p$
Collected into:
28π mm•mrad
$\Delta p/p < \pm 2\%$

Reality Check!

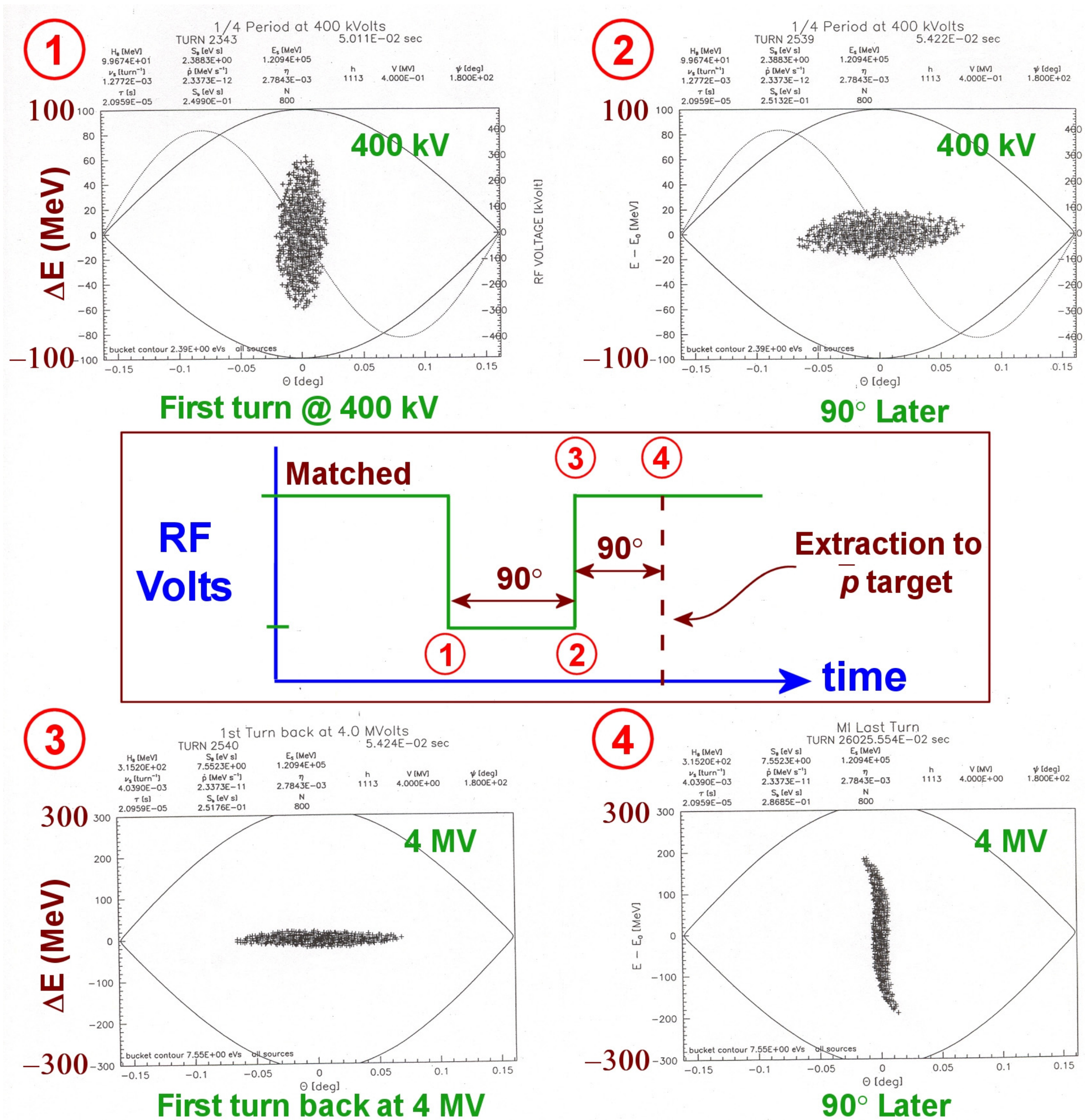
If we were able to accumulate all of these antiprotons, the accumulation rate would be:

$5.0\ \ 10^{12}\,\dfrac{p}{\text{pulse}}$	Protons on target
$\dfrac{1\ \text{pulse}}{1.5\ \text{sec}}$	MI Repetition Rate
$21.7\ \ 10\ ^{6}\,\dfrac{\bar{p}}{p}$	$\bar{p}$ yield from target station
$\dfrac{3600\text{sec}}{hour}$	
$26\ \ 10^{10}\,\bar{p}/hour$	

$$\boxed{\textbf{Best rate so far} = 7.5\times10^{10}\ \bar{p}/\text{hour}}$$

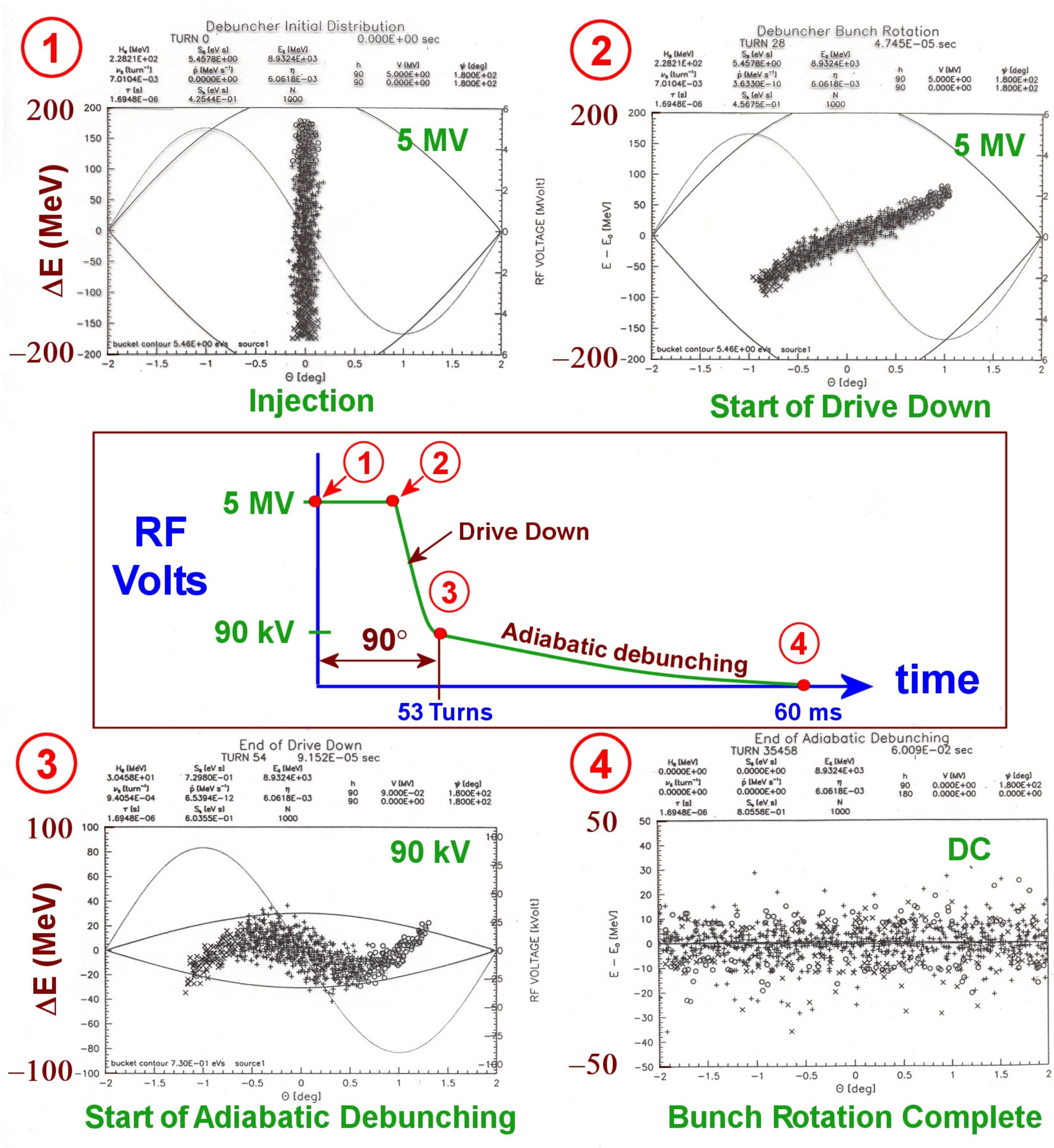


Main Injector Bunch Narrowing

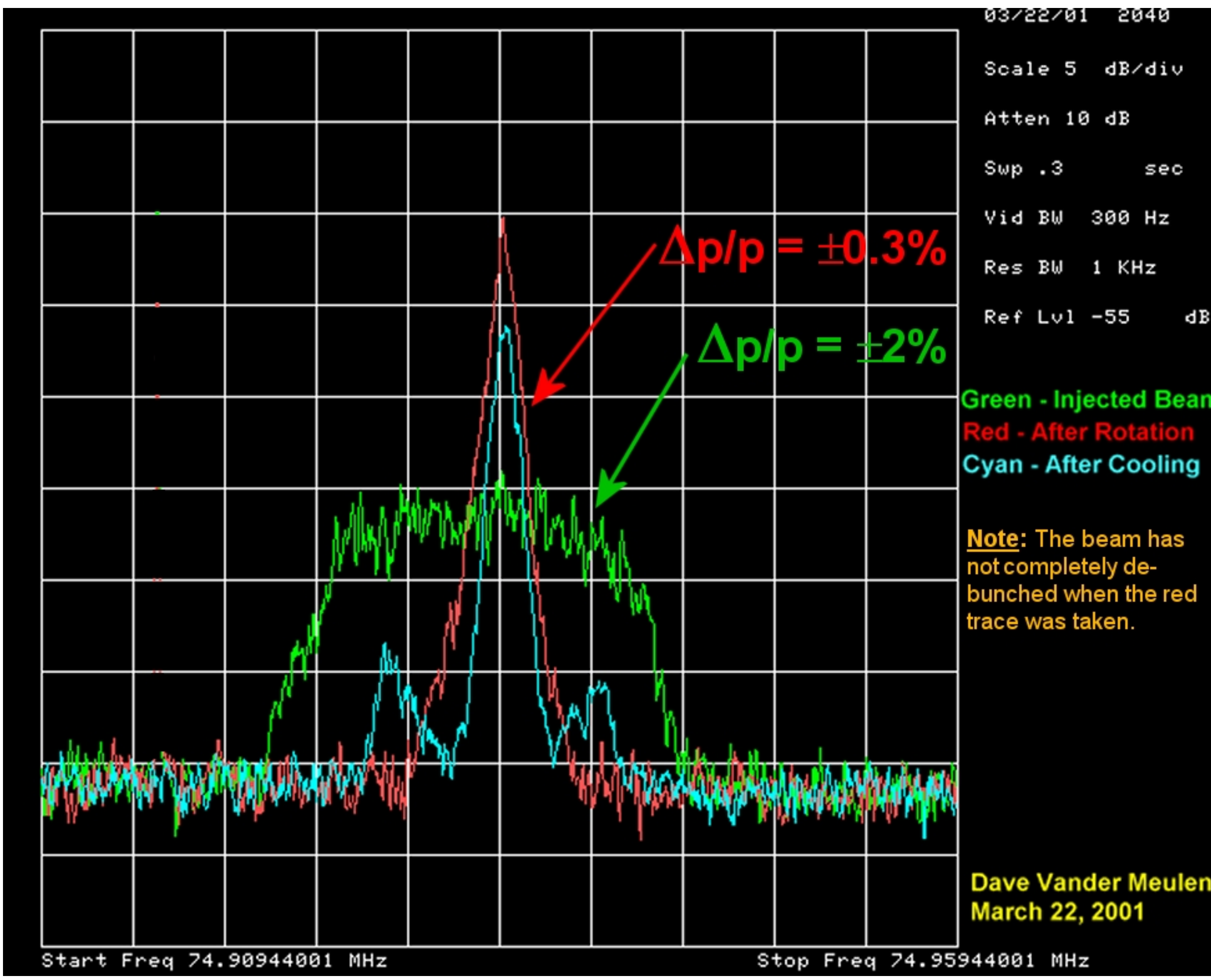


S. J. Werkema

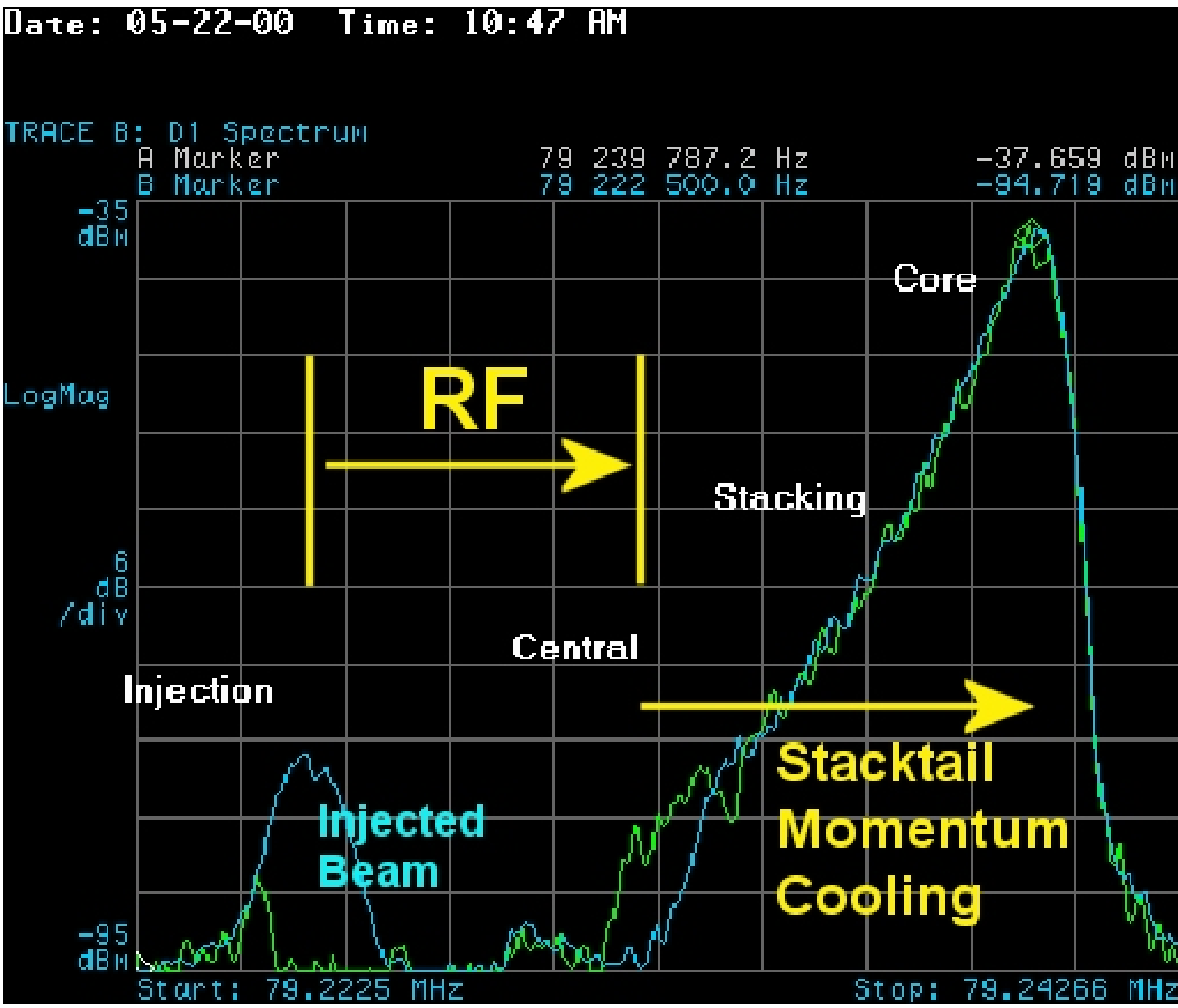
Debuncher Bunch Rotation

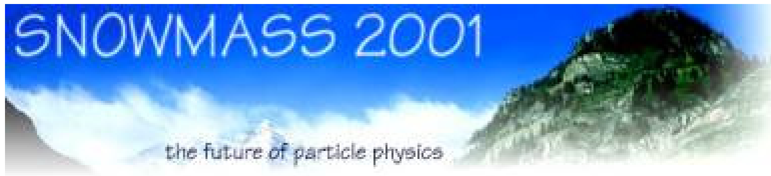


End Result of Bunch Rotation



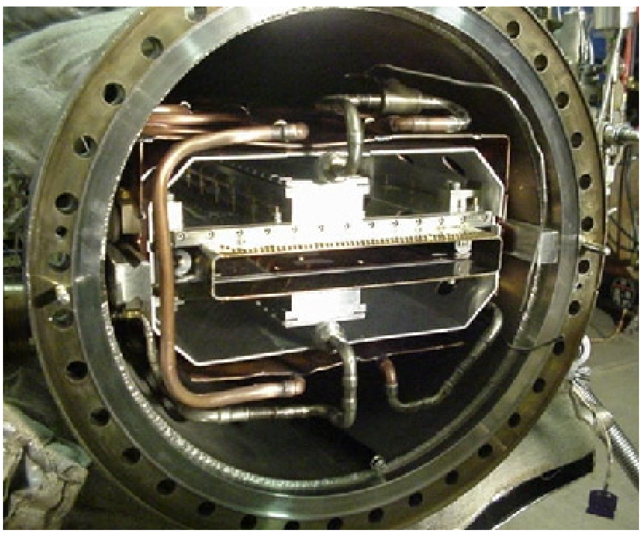
Overview of Momentum Stacking

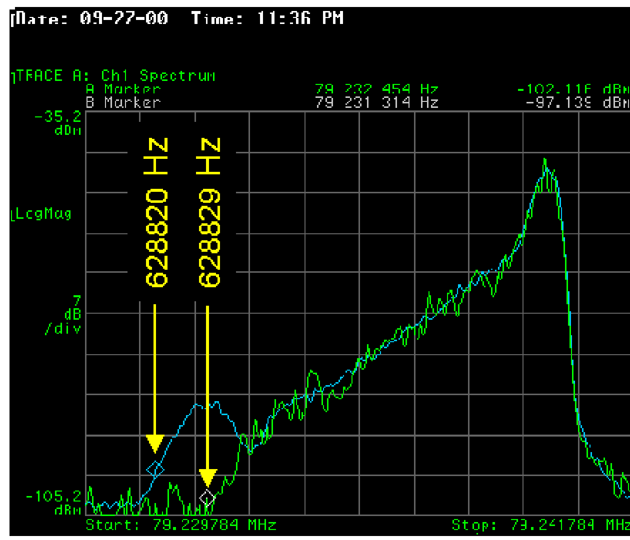




Stacktail Momentum Cooling

2-4 GHz Stacktail momentum pickup





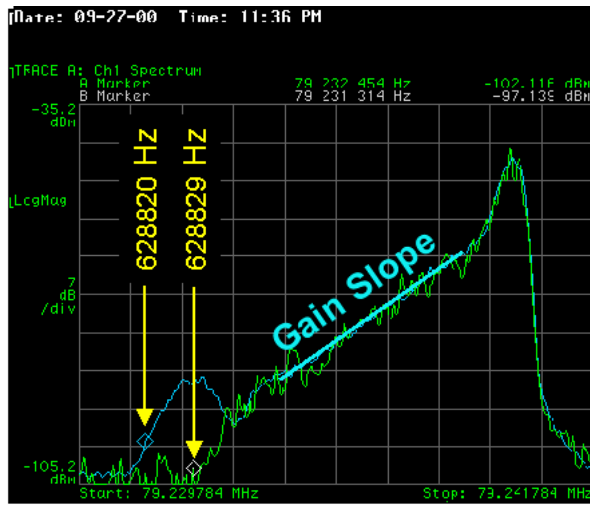
- Stacktail momentum cooling must move newly deposited beam off of the central orbit before the arrival of the next pulse.
- Stacktail cooling pickups must be sensitive to beam in the tail while being minimally sensitive to beam at the core. Any signal from the core results in heating of the core by the stacktail cooling kickers.

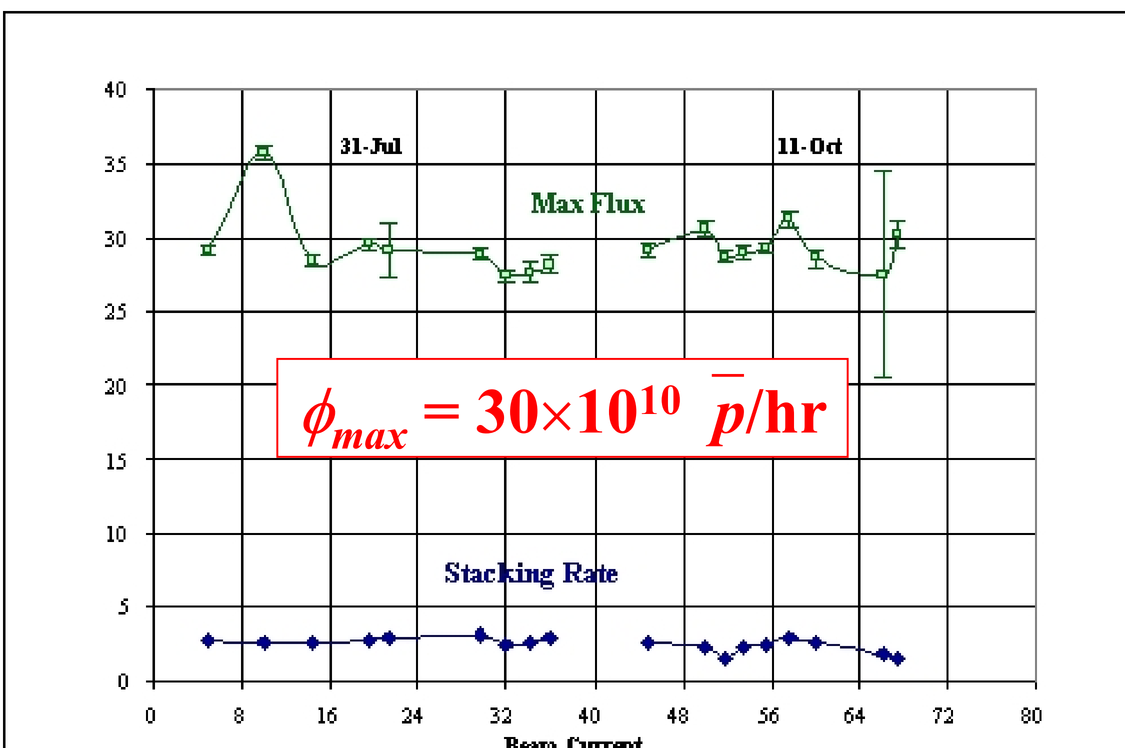
Stacktail Gain Slope

$$(E) \qquad {}_0 e^{\frac{E \quad E_0}{E_d}}$$

- The maximum $\bar{p}$ flux is related to the slope of the density distribution.
- If $\bar{p}$ density distribution is $\psi(E)$ then the maximum flux that can be transmitted is:

$$_{\max} \qquad \frac{\left| \; \right|}{4} \frac{W^2}{f_0} \frac{E_d}{pc} \frac{1}{\ln(f_{\max}/f_{\min})}$$





Summary of Present Performance

Protons on Target	4.5×10^{12} p/pulse
Cycle Time	1.5 – 4 sec/pulse
Production Efficiency	$10 - 12 \times10^{-6}$ $\bar{p}/p$ (Best = 18)
$\bar{p}$ Stacking Rate	7.5×10^{10} $\bar{p}$/hr

Prospects for improvement

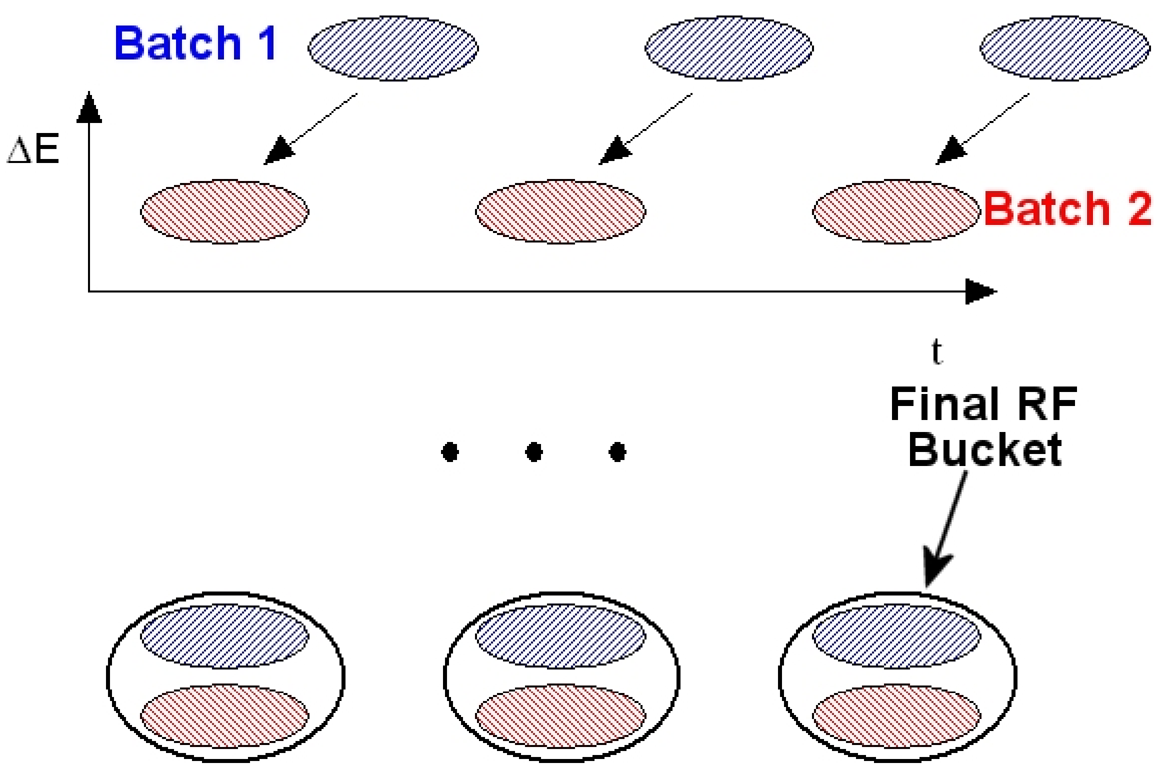
1. More protons on target
   - Brighter proton source
   - Slip stacking
   - ⇒ Target station upgrades:
     - proton beam sweeping
   - ⇒ Stacktail cooling upgrade
     - increase gain slope to accommodate increased $\bar{p}$ flux
     - This limits the peak stack size
   - ⇒ Recycler Ring required
2. Li Lens redesign
3. Increase aperture downstream of target station
4. Recycle "used" $\bar{p}$'s

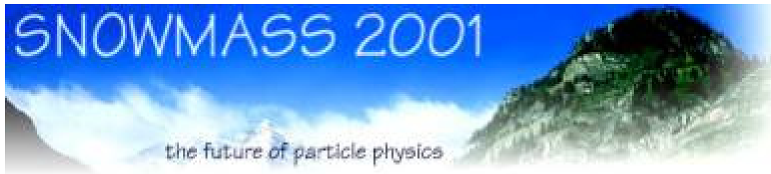
Expected New Stacking Rate:

52×10^{10} $\bar{p}$/hr

Slip Stacking

- Increases the intensity of proton beam by making full use of the large momentum aperture of the Main Injector.
- Two proton bunch trains (batches) are injected into the Main injector. The second batch is injected at a slightly different momentum than the first.
- When the first batch has slipped relative to the second such that the bunches of the two batches aligned azimuthally, the beam is captured in an RF bucket large enough to accommodate bunches from both batches.





Slip Stacking Issues

- Increased beam loading in the Main Injector RF cavities
- Increased proton longitudinal emittance will degrade bunch rotation.